NASA/CR-2001-210641

Data Mining of NASA Boeing 737 Flight Data

Frequency Analysis of In-Flight Recorded Data

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March 2001

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Prepared for Langley Research Center
under Contract NAS1-96013

March 2001

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Abstract

Data recorded during flights of the NASA Trailblazer Boeing 737 have been analyzed to ascertain the presence of aircraft structural responses from various excitations such as the engine, aerodynamic effects, wind gusts and control system operations. The NASA Trailblazer Boeing 737 was chosen as a focus of the study because of a large quantity of its flight data records. The goal of this study was to determine if any aircraft structural characteristics could be identified from flight data collected for measuring non-structural phenomena. A number of such data were examined for spatial and frequency correlation as a means of discovering hidden knowledge of the dynamic behavior of the aircraft. Data recorded from on-board dynamic sensors over a range of flight conditions which showed consistently appearing frequencies inferred those frequencies to be attributed to aircraft structural vibration modes.

CONTENTS

Introduction

This report summarizes the results of data mining from measurements recorded on-board the NASA Trailblazer Boeing 737. A large quantity of available flight recordings exist for this airplane. The goal of this study was to determine if any structural characteristics of the aircraft could be identified from flight data collected for measuring non-structural phenomena. Knowledge discovery in databases (KDD) techniques were instrumental in discovering many hidden characteristics of the aircraft dynamics. The initial successes from KDD were in business use. The growth in the use of KDD is due to lower cost of data storage and processing; the growing rate of data accumulation; and, new data processing methods. In this study, numerous types of data were examined for spatial and frequency correlation as a means of discovering hidden knowledge of the dynamic behavior of the aircraft and its instruments. In dynamic systems, response signatures to disturbances are implicitly "cause-effect" rules. Analysis of data from on-board sensors recorded over a range of flight conditions which showed consistently appearing frequencies considered such frequencies as representing aircraft responses to external excitations. When different sensors with some capability of sensing the same response show a matching consistency in response frequencies, then such measurements would be indications of a structural mode. Within the frequency range from 1.2 to 4.3 Hz, the analysis identified consistently appearing frequencies that suggested structural motion responses. Measurement of such frequencies during flight carry the potential for monitoring aircraft structural health and can provide support to fatigue analysis or predictions.

This paper will present the tools used to discover the aforementioned findings and how they may be used on other aircraft. Following this introduction is a brief overview of NASA Trailblazer Boeing 737. A brief discussion of the knowledge discovery in database techniques will be presented next. Examples of data mining results produced from these techniques in the frequency and spatial domain will follow. These examples include some of the key findings from this study. Following the examples will be conclusions that summarize the lessons learned from this study.

NASA Trailblazer Boeing 737 Overview

The NASA Langley Trailblazer Boeing 737 completed 822 research flights over a period of 22 years. This airplane is now on display at the Boeing Airplane Museum in Seattle, Washington. Airborne Trailblazer[1] summarizes the research and results obtained during the first 20 years of service. Initial studies addressed airspace and air traffic control concerns relative to airports and landing approaches. Theses studies required modifications to the passenger section that included the installation of a second cockpit and flight control station which replaced the first six rows of seats. Configuration flexibility provided this airplane with a capability to evaluate any type of visual aid or special auxiliary while still maintaining its basic integrity. Research performed on the airplane included wind shear, development of internal sensing instrumentation, and operations with external navigation aids. Throughout its active use, it was continuously modified to meet new research requirements and it became one of the "most used" of all research aircraft.

Knowledge Discovery in Databases Overview

Knowledge discovery in databases (KDD) is the non-trivial extraction of implicit, previously unknown, and potentially useful information from data.[2] It is the process of discovering hidden knowledge, unexpected patterns, data clusters and new "cause-effect" rules from large databases. Knowledge discovery in databases has six stages: data selection, data cleaning, data enrichment, coding, data mining and reporting.[2] Data selection is the stage of selecting the right data for KDD. In this study, data selection consisted of selecting the telemetry records from the flight data archives at NASA Langley Research Center. Data cleaning is the process of removing noise, errors, and incorrect input from a database. For example, some instrument data had vibrational perturbations superimposed upon the rigid-body rotational motion. The rigid-body motion was removed from rotational data to analyze its vibrational behavior. Data enrichment is the process in which new data is added to the existing selected data. The data enrichment process was not used in this study. Coding transforms or simplifies data in order to prepare it for analysis and/or machine learning. All analysis performed by NASA was with the Matlab numeric computation and visualization software by the Math Works, Inc.[3]

The next stage is that of data mining. Data mining is the actual discovery phase. Goals of data mining include identifying and/or discovering structure, characteristics, tendencies, anomalies and relationships among data. A myriad of techniques can be used for data mining. These can include statistical, machine learning, visualization (e.g., scatter plots), pattern recognition and clustering tools. Data mining can be used to identify behavior rules of databases (i.e., "cause-effect" rules). Reporting is the application of using results from data mining to modify or redirect the mining algorithm to examine new data or examine data in a new manner. Discovery of characteristics to spacecraft dynamics can be used to hypothesize the existence of other features. Hence, the database can be further mined for proof of new hypotheses. Because the database is a record of physical phenomena, data mining can also be the genesis to experimentation.

Another key element of KDD is the data warehousing. Data warehousing is the repository of historic subject-oriented data. A data warehouse is designed for decision support. Data in a data warehouse is nonvolatile, integrated, subject–oriented and time-dependent.

Analysis Approach

Spectral analysis using power spectral density (PSD) of flight data was the principal tool used throughout the study. All NASA Trailblazer Boeing 737 data had a sampling rate of 20 Hz. An initial review of flight data showed evidence of some instrument mounting resonances beginning at 5 Hz. A practical upper limit of 4.3 Hz was used for aircraft structural response identification. Motion responses below 1.5 Hz were assumed to be rigid-body. Observations from commercial airline flights give indications of structural resonances within such a frequency range. In flight, wings take visible static deflections; turbulence superimposes wingtip oscillations which show a frequency near 2 Hz. Aerodynamic loading coupled with engine noise generates low level random excitations throughout the airplane. Turbulence excites higher level transients as combinations of rigid body motions and structural resonances. Thus, existing recorded flight data may not always contain structural responses at levels sufficient to detect. In many cases, structural resonant responses appeared at levels well below those for rigid body motions.

Selection of flight data for analysis first sought representative flight conditions. Data records from two flights were used; a steady-state level flight (Flight 732); and a glide slope approach to an airport landing (Flight 809). Table 1 summarizes the defining parameters for each segment. Flight conditions were determined from 22 measurements; data included flight velocities, headings, altitudes, attitudes with their rates, accelerations and control surface positions plus the externals of wind direction and wind velocities. Only the three accelerations and four rate sensors (e.g., gyro outputs for altitude, pitch, roll and yaw) had sufficient resolution to be used with the frequency analysis. All other data had higher thresholds of resolution (e.g., an altitude change appeared as a stair-step plot). Consequently, data from these seven sensors became the basis for frequency analysis. Table 2 summarizes the types of interactions and corresponding sensitivities of data to structural resonances.

Aircraft structural resonance frequencies will show minor variations due to changes in on-board load (e.g. fuel consumption). In addition, structural damping will broaden the range of a resonant frequency response. A frequency error increment of 0.1 Hz was considered an identity in comparing frequencies from PSDs.

Separation of low frequency rigid body motions and control interactions from structural responses required frequency analysis over three ranges. Low frequency (0.02 to 1.0 Hz) identified rigid body motions and showed any control interaction frequencies. Midrange (0.7 to 2.1 Hz) accommodated the rigid body motions and served to identify any potential structural resonances. The high frequency range (1.7 to 5.0 Hz) addressed very low responses to identify frequencies that could be indications of structural resonances.

For this analysis, selection of six overall segments with 2048 data points (102.4 s) each simplified characterization of low frequency rigid body motions by effectively limiting the number of modulating frequencies that could appear[4]. Utilization of three frequency ranges across the frequencies of interest allowed separation of rigid body motion and related harmonics from the low level responses anticipated from structural resonances. Over the frequency range for potential structural resonances, limiting the number of modulating frequencies enhanced the identification of frequency peaks that could indicate responses to structural resonances. It is recognized that analysis based upon data samples of other lengths or other time intervals would not show the same PSD response amplitude patterns; however, within the frequency range of interest, consistencies of frequencies within responses would be the same (e.g., same frequencies, different amplitude peaks). Therefore, this analysis consisted of the following steps and actions:

1. Verify that the PSDs of data from each sensor showed consistent frequency differences within each of the six segments selected for the analysis. (A chaotic input converted into a finite set of interacting frequencies)

2. Compare the data output from sensors with the low frequency range PSD to identify the principal frequency content and associated periodicity together with their harmonics.

3. Evaluate the mid and high range PSDs toward identification of frequencies that could represent interactions with, or evidence of, structural resonances.

4. Identify frequencies that appear in both the Level Flight and Norfolk Approach PSDs and determine the overall degree of consistent appearance. (Use 0.1 Hz as the range for identical frequencies and 66 percent as the measure for the measure for consistent appearance)

5. Review consistently appearing frequencies from each sensor for correlation with similar results from the other sensors and evaluate for indications of structural resonances.

Analysis Results

A detailed survey of PSDs from all seven sensors showed consistent sets of frequency differences. Recorded data from sensors together with their PSDs appear in Figures 1 through 8. Descriptions which follow show the actions and evaluations to accomplish Steps 2 and 3 and provide the input to Step 4. Evaluations begin with longitudinal accelerations (Fig. 1 through 4) which are considered to represent the external excitations of the airplane. Roll Rate responses (Fig. 5 through 8) are considered representative of the other six sensors in showing interactions with control systems. Longitudinal accelerations in the direction of flight do not couple directly with any of the resonances anticipated in the frequency range considered. Longitudinal accelerations do present a summary of airplane reactions during encounters with wind gust excitations. Comparisons of longitudinal acceleration measurements with wind velocities and changes in flight velocities show similarities. Data traces from the other six sensor have the form of regular continuous waves that suggest interactions with aircraft control systems as well as external excitations.

Data from the longitudinal accelerometer are shown in Figure 1 for 102.4 second intervals during Level Flight and Norfolk Approach. Within this study, the segment shown for Level Flight represents the minimum excitation encountered; the segment shown for Norfolk Approach represents the maximum excitation encountered. Level Flight indicates an encounter with a long duration gust (e.g., 70 seconds) with smaller, shorter-duration disturbances within the main wave. The combination results in an acceleration excursion of about 0.5 ft/s^2. A secondary acceleration disturbance rides on the main wave with a total amplitude of about 0.1 ft/s^2. This data trace shows an accelerometer resolution of 0.01 ft/s^2. In contrast, Norfolk Approach represents the last segment of a bumpy ride to a landing. This trace shows a long term gust carrying multi-frequency disturbances. Acceleration excursions from disturbances range from 1.5 to 2.0 ft/s^2; total excursions exceed 3.0 ft/s^2.

These effects appear in the low frequency range PSDs shown in Figure 2. For Level Flight, the lowest resolvable frequency which would allow frequency identifications up to 1.0 Hz appeared at 0.065 Hz with a corresponding period of 15.38 seconds. This interval correlates to the valley-to-valley interval between 57 and 72 seconds as recorded in the accelerometer trace (Fig. 1a). Roll-off harmonics of this frequency can be identified. The secondary disturbance shows a complex wave with a dominant frequency of 0.419 Hz. corresponding to a period of 2.38 Hz. Harmonics can be identified; however, a careful examination of the trace shows an appearance that indicates both frequency and amplitude modulations. Norfolk Approach low frequency content shows a principal response at 0.052 Hz with a period of 19.23 seconds which correlates to an average interval between the major peaks or valleys in the accelerometer trace. A second strong periodicity response appears at 0.166 Hz with a period of 6.02 seconds which correlates to the secondary peaks and valleys that appear superimposed upon the larger excursions within the accelerometer data trace

(Fig. 1b). The low frequency range PSDs show the differences in airplane excitation levels and excitation frequency content; therefore, PSDs for the higher frequency content which is apparent within each of the accelerometer traces can be expected to show different patterns of response amplitudes.

Mid Frequency Range PSDs presented in Figure 3 show such predicted differences in responses and make transitions from low-frequency, rigid-body effects into the frequency range for potential structural resonance responses . At 1.0 Hz, Level Flight responses have rolled off to values just above the limit of sensitivity (e.g., 0.0001 for a 0.01 sensor). Norfolk Approach responses continue to roll off over frequencies up to 2 Hz where they reach a level that generates PSD values about an order-of-magnitude above those for Level Flight. Evaluation for consistently appearing frequencies as indications of potential structural resonance responses arbitrarily began at 1.2 Hz; such frequencies appear and are identified in both PSDs. Figure 4 shows the PSDs over the principal frequency range of interest. In a comparison, amplitudes and amplitude patterns do not correlate while frequencies within the response patterns do correlate. Criteria for selecting frequency peaks for correlation considered stand-alone peaks, peaks that did not fit into local patterns and peaks that seemed to show a local substructure. Frequencies that appeared consistently in both Level Flight and Norfolk Approach are identified. Consistently appearing frequencies are considered as potential indicators of structural resonances. A consistent frequency had to appear in both Level Flight and Norfolk Approach segments, and in addition, it had to appear four of the six data segments utilized for this analysis.

Traces from the roll rate sensor over the same time intervals are shown in Figure 5; these traces are considered typical for the six sensors which responded to control system interactions. All six sensor traces appear in the form of continuous waves which visibly display both amplitude and frequency modulations. Roll rate Level Flight (Fig. 5a) responses measure in tenths of a degree-per-second as compared to the bumpy Norfolk Approach (Fig. 5b) responses in whole degrees-per-second. Times for the amplitude modulation peaks in Level Flight correspond to the two maximum rate of change times in longitudinal acceleration (e.g., 27 seconds, 82 seconds) and the inflection point near 50 seconds. Norfolk Approach amplitude peaks correlate to the longitudinal acceleration transients at 190, 240 and 265 seconds. In both cases, longitudinal accelerations and roll rates are showing their particular responses to the same external excitations.

Low frequency Range PSDs shown in Figure 6 also reflect such timings in their frequency content. For Level Flight (Fig. 6a), the lowest resolved frequency of 0.047 Hz has a period of 21.2 seconds which matches the longitudinal acceleration time interval between the first maximum rate of change (27 seconds) and inflection point (50 seconds). Average periodicity at 0.212 Hz has a period of 4.7 seconds to suggest an interaction with a control system; the overall PSD indicates a complex interaction involving the observed periodicity and its harmonics. Norfolk Approach (Fig. 6b) shows a more complex interaction. The lowest resolved frequency of 0.021 Hz has a period of 47.6 seconds which correlates to the time interval between the peak sensor trace excursion at 195 seconds and the peak sensor trace excursion at 242 seconds (Fig. 5b). A frequency of 0.021 Hz appears consistently in the frequency differences throughout the total PSD. The maximum response frequency of 0.164 Hz has a period of 6.09 seconds; the average periodicity, 0.227 Hz, has a period of 4.40 seconds; both of these values appear in elapsed times between peaks or valleys within the roll sensor trace. Both values suggest interactions with control systems; multi-frequency responses of this type have been shown to occur[4]. These three frequencies together with their harmonics and interactions define the low-frequency, rigid-body roll motions during this segment of Norfolk Approach.

Mid frequency range PSD renderings, Figure 7, show the continuing roll-off of responses down to the low levels associated with structural resonances. Identification of frequencies potentially responding to structural resonances used the same criteria outlined for longitudinal acceleration. The high frequency range PSDs, Figure 8, identify those frequencies which could be responding to structural resonances and further define those frequencies which consistently appear in both Level Flight and Norfolk Approach recorded data. In comparing the two roll rate response patterns, differences in airplane excitations result in an order-of- magnitude difference in values for PSD peaks; the values shown for this segment of Level Flight are considered just above threshold for discrimination.

PSDs from all seven sensors received the evaluation and analysis outlined above across each of the six 102.4 second time segments selected for this study (e.g., four for Level Flight, two for Norfolk Approach). Step 4 actions began with compiling a side-by-side listing of the identified frequencies from each sensor across all six time segments. Initially, frequency listings were in terms of even 0.1 Hz increments over the range 1.2 to 4.3 Hz; however, evaluations to identify frequencies appearing in both Level Flight and Norfolk Approach and subsequently for consistency in appearance considered a 0.1 Hz range as an identity. Consistently appearing frequencies were readily identified; such a determination completed Step 4 and allowed a final comparison.

Comparison evaluations of consistently appearing frequencies (Step 5) began with the compilation of individual sensor determinations shown in Table 3. Results from each sensor are listed in frequency increments of even 0.1 Hz (other 0.1 Hz frequency range increments are identified where applicable). Consistencies are listed in terms of percentage for appearance of frequencies within such 0.1 Hz increments across the total recorded time with 66 percent (e.g., frequency appears in four of the six time segments as well as in both flight conditions) as the threshold for consideration. Within the overall compilation shown in Table 3, each sensor reveals a pattern consisting of broad frequency responses and narrow-band peaks.

Cross correlation as matching responses to the same frequency increments appear in responses from sensors in the vertical plane (e.g., normal (vertical) acceleration, altitude and pitch rates) and also for the horizontal plane (e.g., lateral acceleration and yaw rate). Longitudinal acceleration shows a broad frequency response which indicates responses to characteristic frequencies from within the airplane itself as well as external excitations. Consistently appearing frequencies do result from external excitations of the airplane but are characteristics of the airplane and not mirrors of encountered excitations. It is recognized that any external excitation will generate these patterns of constantly appearing frequencies; however, the amplitudes of individual frequency responses will be determined by the content (e.g., wave shape and amplitude) of that external excitation. A review of consistently appearing frequency patterns over the range 1.2 to 4.3 Hz allows the following observations an assessments.

Frequencies from 1.2 to 2.2 Hz.

An overall general response suggests these are due to rigid body motions and confirms the assumption of a stiff structure.

Frequencies from 2.3 to 3.5 Hz.

Over this range, roll rate shows a minimum of response while pitch, yaw and altitude rates together with accelerations are generally active. Such patterns suggests motions in the vertical and horizontal planes. Wing bending could account for the pattern observed from 2.4 to 2.7 Hz. normal (vertical) acceleration, altitude and pitch rates are active. Roll rate shows responses at 2.5 and 2.6 Hz; and roll excursions tend to accompany excitations of wing bending. From 2.8 to 3.2 Hz, there is no consistent roll rate response while normal (vertical) acceleration, altitude and pitch rates show agreements. This pattern suggests a fuselage first bending mode centered near 3.0 Hz. Throughout this range, lateral acceleration and yaw rate responses show such a close agreement as to suggest they are responding to the same excitation and the airplane is still a rigid body in the horizontal plane (e.g., a very stiff airplane).

Frequencies of 3.6 and 3.7 Hz.

An indication of roll motion with scattered responses elsewhere suggests a possible fuselage torsional mode.

Frequencies from 3.7 to 4.3 Hz.

Over this range lateral acceleration and yaw rate show a close correlation with scattered responses from the other sensors. Such a pattern suggests responses to a fuselage bending mode in the horizontal plane.

Conclusions

For frequencies below 1.0 Hz, this study has outlined a means to characterize aircraft responses in terms of principal frequencies and their relative amplitudes. For frequencies in the range of anticipated structural resonances where such data resides in low level indications, this study has concluded that extracting aircraft dynamic response from flight data is not feasible unless the data can be corroborated with other information about the aircraft and its systems. This information was not available. A PSD-based technique was used for identification of potentially structural frequencies. A comparison compilation of potential frequencies then allowed further identification of consistently appearing frequencies which were then considered as characteristic. For this analysis, an evaluation of identified characteristic frequencies from seven sensors suggested responses to motions generated by the structural modes of the airplane. No opportunity exists to compare these results with earlier data or analysis. In assessing the value of this PSD-based technique for data mining, it is tedious and its effective use is limited to cases which only require the identification of hidden frequencies within a data stream; correlation of input excitation to response amplitude is not a capability. On the other hand, this technique showed evidence of structural resonances within the data from sensors never intended for such measurements and not specifically located to sense structural resonances. The results, thereby, confirm that an airplane will respond characteristically to external excitations and knowledge of in-flight excitation-to-response relationships will have value.

In assessing the potential value of in-flight measurements of structural responses, commercial airplane usage dictates operations over long periods of time (e.g., decades). Initial designs must consider long term fatigue effects yet commercial operations do not have an effective means to obtain fatigue-related data. Until recently, detail flight measurements implied a near-dedicated aircraft carrying an extensive array of hard-wired instrumentation and on-board recording equipment. In considering measurements from research aircraft, it is recognized that research airplanes do not accumulate flight times associated with airline operations; however in the course of research studies, research airplanes can be subjected to flight environments which airline operations carefully avoid.

For the NASA Trailblazer Boeing 737, the consistently appearing frequencies gave indications of responses to structural resonances from sensors intended for other research purposes. On the other hand, recent developments in instrumentation and recording capabilities could provide a direct approach to measurements of structural excitations and responses.

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TABLE 1: SUMMARY OF FLIGHT CONDITIONS FOR DATA USED IN FREQUENCY ANALYSIS

Flight Number	R732	R809
Date Flown	Sept. 21, 1994	Apr. 30, 1997
Location	Denver, CO	Approach to Norfolk, VA
Altitude	33,000 ft	Descent, 2500 to 500 ft
Airspeed	440 kt	145 kt
Wind Speed	70 to 80 kt	12 to 30 kt
Direction Rel. to Flight	60 to 70 deg	0 to 10 deg
Gust Durations	20 to 100 s .	5 to 20 s
Total Recorded Time	378.5 s	182.9 s

TABLE 2: ASSESSMENT OF MEASUREMENT SENSING DIRECTIONS RELATIVE TO STRUCTURAL RESONANCE MOTIONS

Principal Structural Resonances Anticipated During Flight

Measurement Parameter	Wing Bending	Fuselage Vertical Bending	Fuselage Horizontal Bending	Fuselage Torsion
Longitudinal Acceleration	Perpendicular	Perpendicular	Perpendicular	Perpendicular
Vertical Accel.	Parallel	Parallel	Perpendicular	Partial
Lateral Accel.	Perpendicular	Perpendicular	Parallel	Partial
Altitude Rate	Parallel	Parallel	Perpendicular	Partial
Pitch Rate	Partial	Parallel	Perpendicular	Perpendicular
Roll Rate	Partial	Perpendicular	Perpendicular	Parallel
Yaw Rate	Perpendicular	Perpendicular	Parallel	Perpendicular

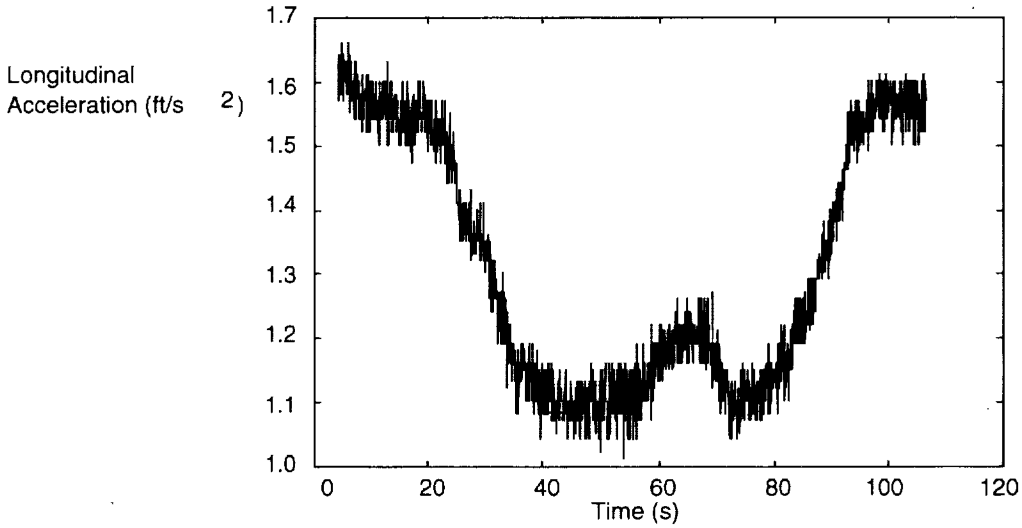
TABLE 3, COMMONALITY OF OBSERVED FREQUENCIES

Flight Sensor Data Analysed Using PSD

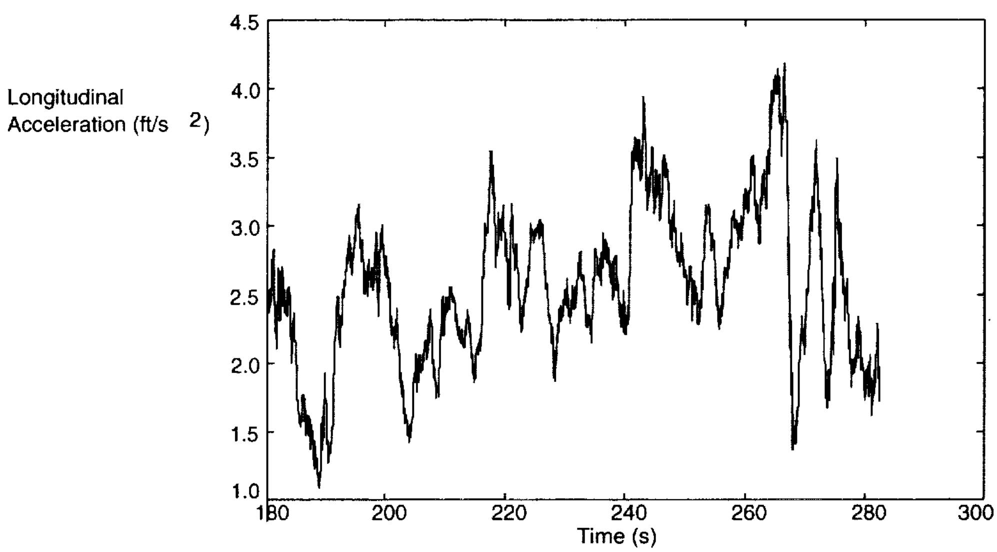
Frequency Increments of 0.1 Hz	Long. Accel.	Vert. Accel.	Lat. Accel.	Alt. Rate	Pitch Rate	Roll Rate	Yaw Rate
1.2			66*		66		83
1.3	66			66			100
1.4				66		83	100
1.5		83	83		83	83	
1.6					66	83	
1.7	83	100	83		66	100	83
1.8	100	83			100		
1.9	66	100	83	100	83	100	66
2.0			100		66	66	100
2.1	66	83	66	83	66	83	
2.2	66		83	83	100		83
2.3	66					66	66
2.4	66			83	83		66
2.5	66	83	66	100		83	
2.6	66	83			66	83	
2.7	83	66	66	83	66		66
2.8			100	83	66		83
2.9		100**	100**	100**	100**		
3.0	83	100**	100**	100**	100**		100
3.1		66	66	66			
3.2	66	83		100	66		
3.3	83		100				100
3.4		83	83		66		83
3.5				66			
3.6	83	100	66		66	66	
3.7			83			66	100
3.8		66	83		66		66
3.9	83		83				66
4.0		66	66	83		83	66
4.1	83	83	83	66			83
4.2				83		100	
4.3			66	100			

*PSD frequency analysis identifies a response in the range 1.2 to 1.3 Hz etc. which appears in both Level Flight and Norfolk Approach data and also appears over 66, 83, 100 percent of the total recorded time.

** These frequencies fall within the 0.1 Hz range from 2.95 to 3.05 Hz.

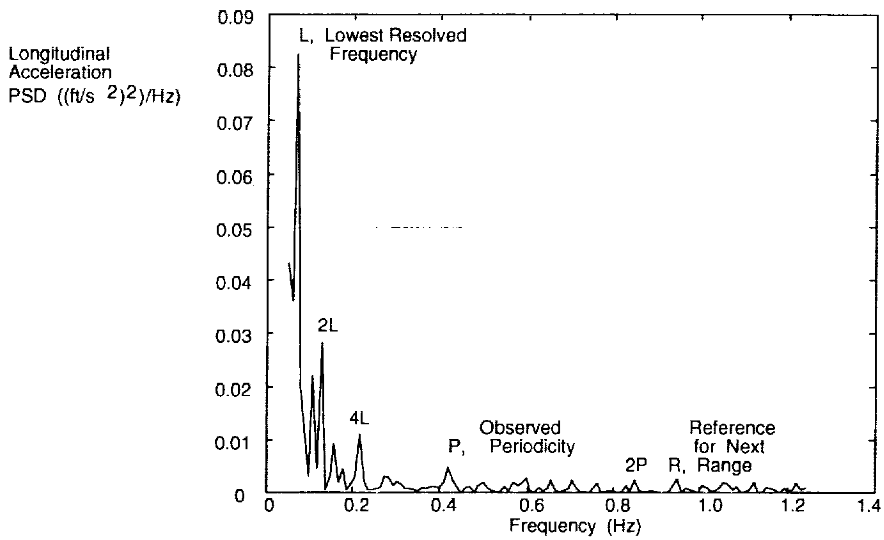


a. Level Flight during Flight 732.



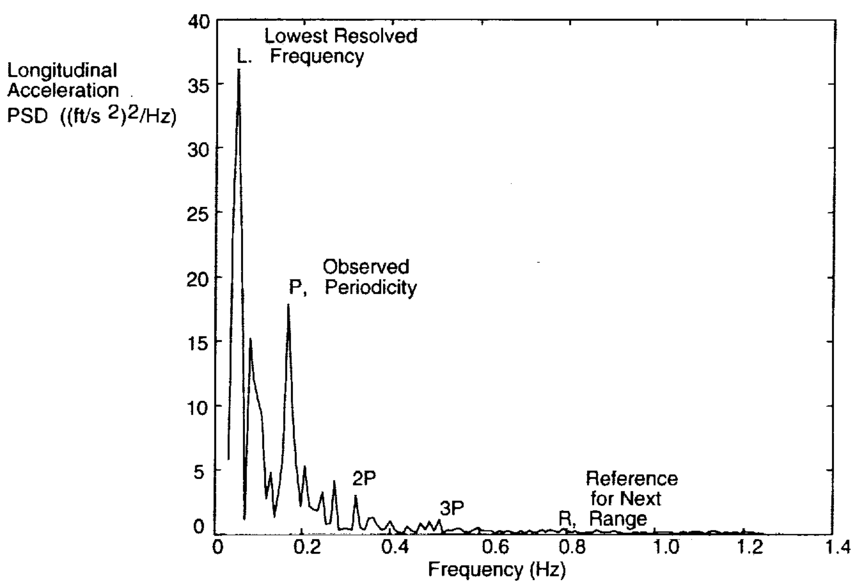
b. Norfolk Approach during Flight 809.

Fig. 1, Longitudinal Acceleration



Frequencies (Hz): L = 0.065, 2L = 0.125, 4L = 0.213, P = 0.419, 2P = 0.843, R = 0.955

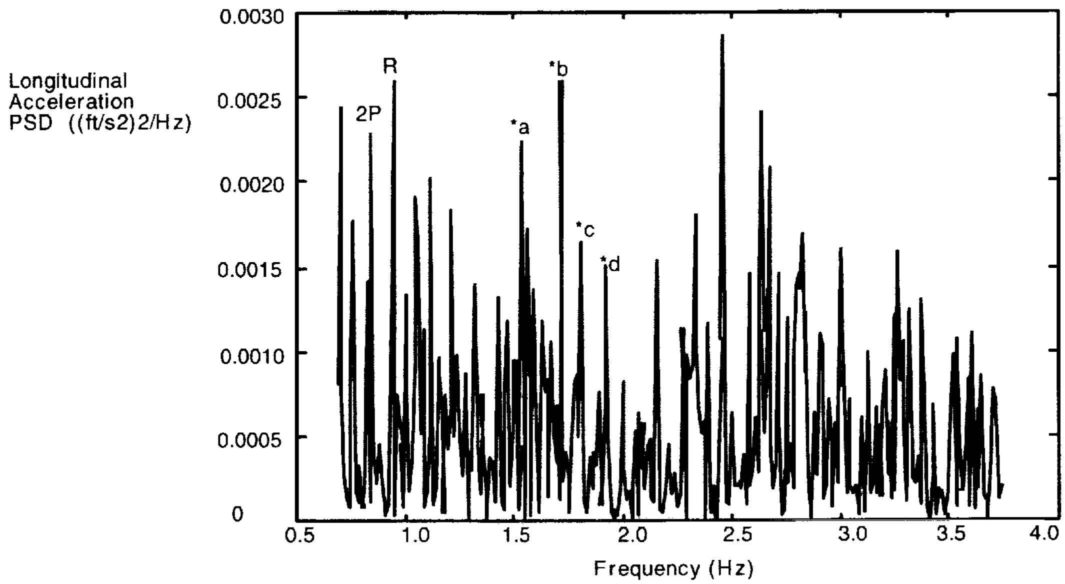
a. Level Flight during Flight 732.



Frequencies (Hz): L = 0.052, P = 0.166, 2P =0.321, 3P = 0.515, R = 0.797

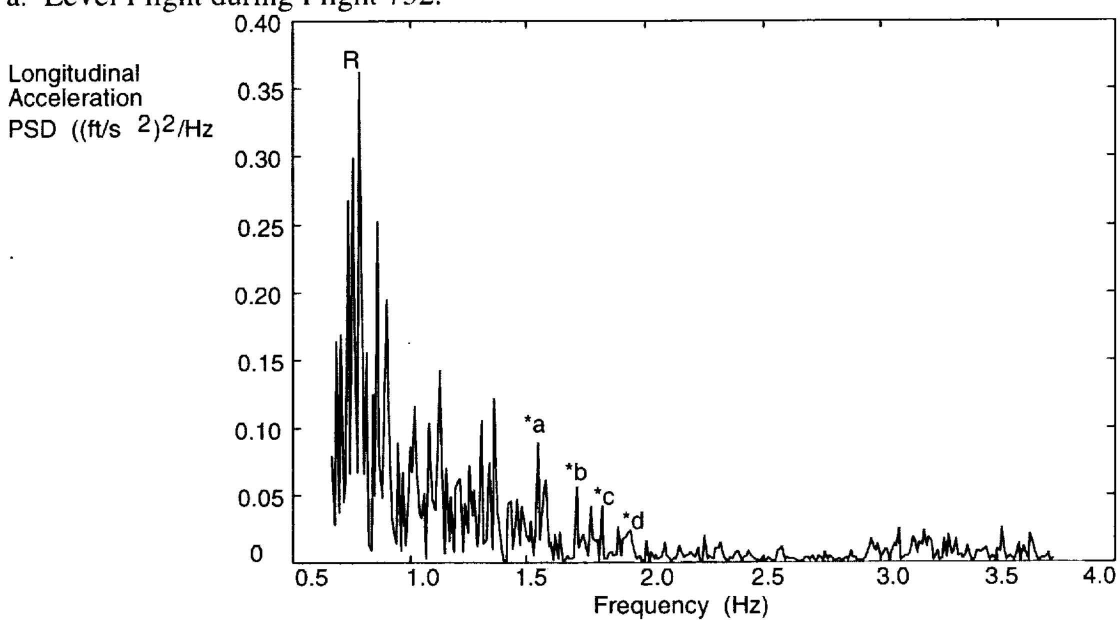
b. Norfolk Approach during Flight 809

Fig. 2, Longitudinal Acceleration PSD, Low Frequency Range, (0.05 to 1.0 Hz)



Frequencies (Hz): 2P = 0.843, R = 0.955, *a = 1.542, *b = 1.730, *c = 1.816, *d = 1.935

a. Level Flight during Flight 732.

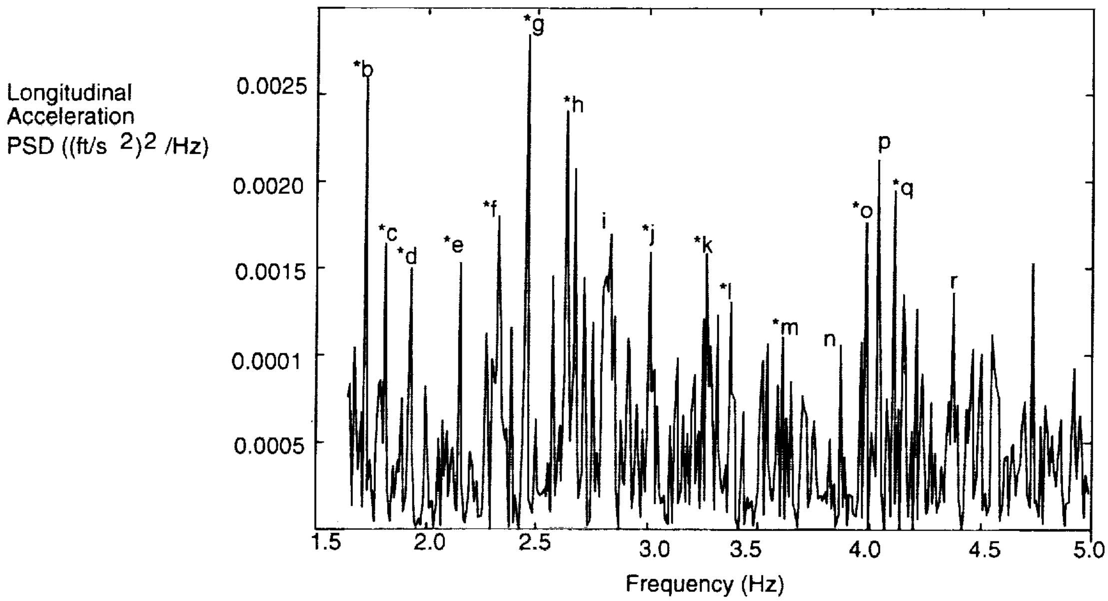


Frequencies (Hz): R = 0.797, *a = 1.555, *b = 1.717, *c = 1.836, *d = 1.948

b. Norfolk Approach during Flight 809

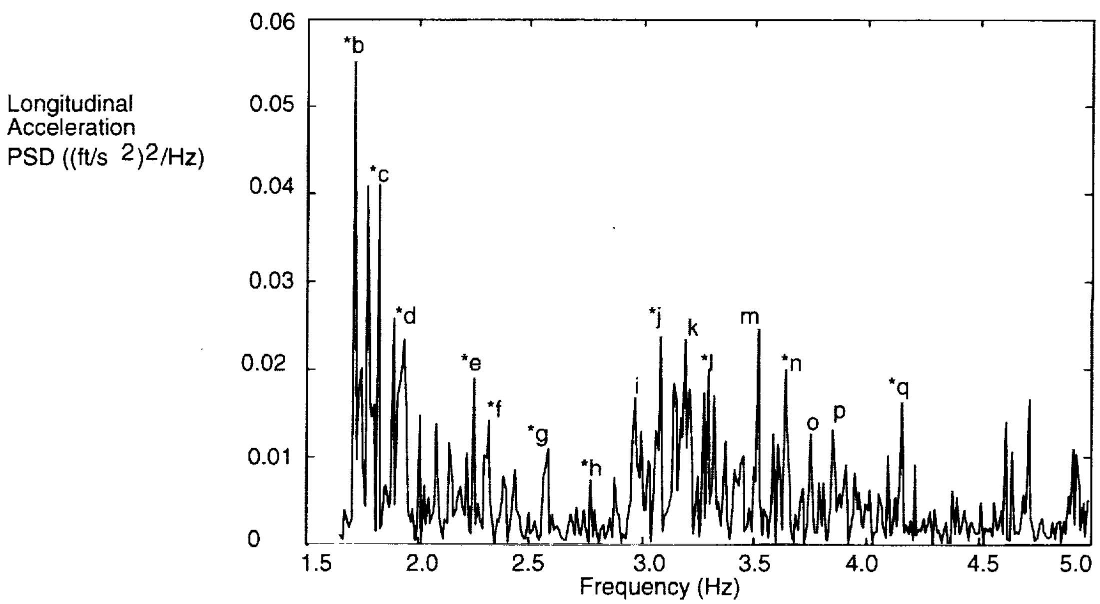
(*) Identifies frequencies which appear in PSD renderings from both Flights

Fig. 3, Longitudinal Acceleration PSD, Mid Frequency Range, (0.7 to 2.1 Hz)



Frequencies (Hz): *b = 1.730, *c = 1.816, *d = 1.935, *e = 2.152, *f = 2.344, *g = 2.462, *h = 2.647, i = 2.831, *j = 3.009, *k = 3.297, *l = 3.385, *m = 3.616, n = 3.885,*o = 3.984, p = 4.051, *q = 4.112, r = 4.379

a. Level Flight during Flight 732

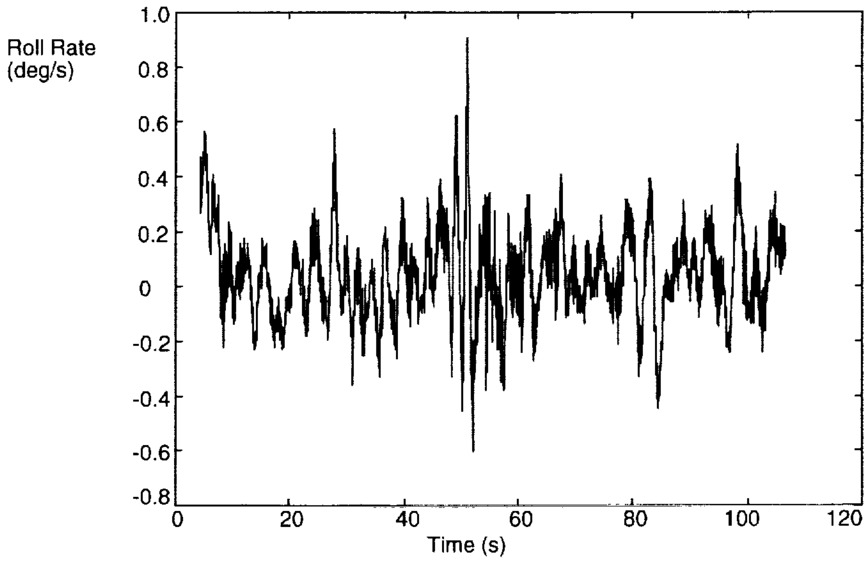


Frequencies (Hz): *b = 1.717, *c = 1.836, *d = 1.948, *e = 2.265, *f = 2.317, *g = 2.588, *h = 2.779, i = 2.963, *j = 3.082, k = 3.187, *l = 3.293, m = 3.537, *n = 3.635, o = 3.760, p = 3.853, *q = 4.156,

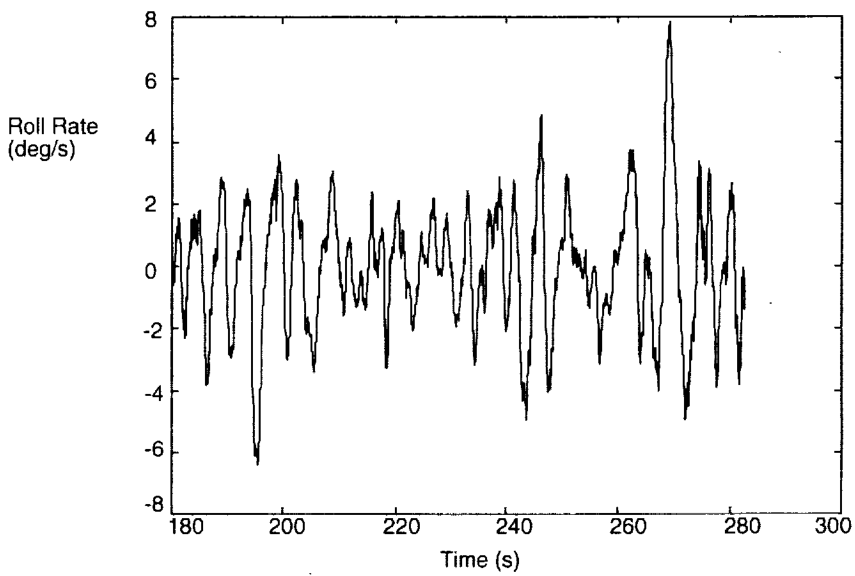
b. Norfolk Approach during Flight 809

(*) Identifies frequencies which appear in PSD renderings from both Flights

Fig. 4, Longitudinal Acceleration PSD, High Frequency Range, (1.7 to 5.0 Hz)

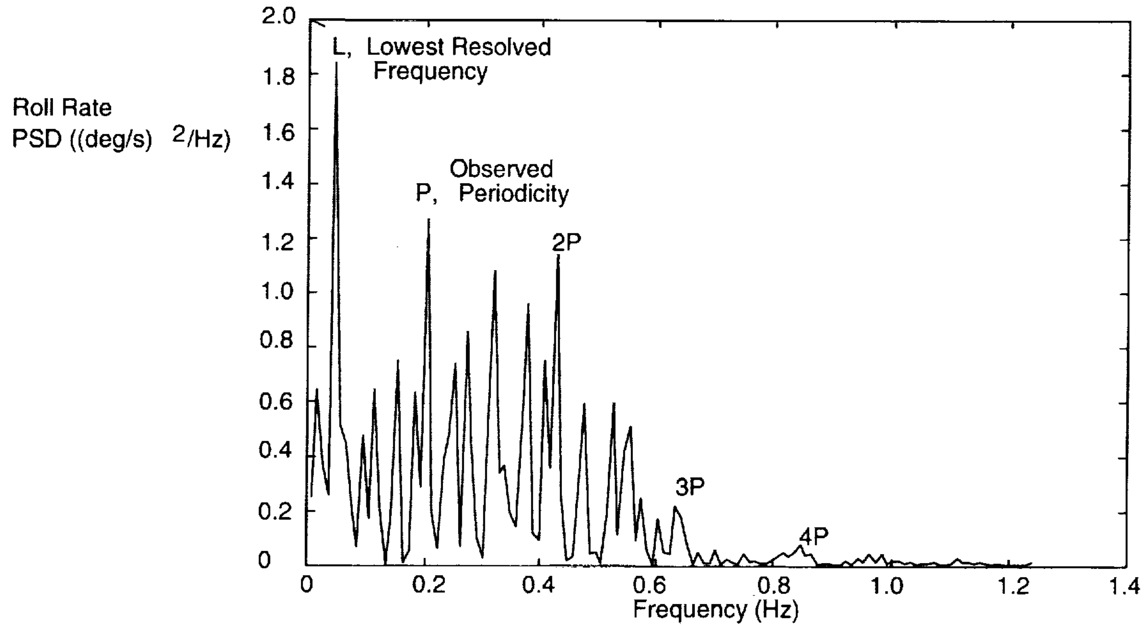


a. Level Flight during Flight 732



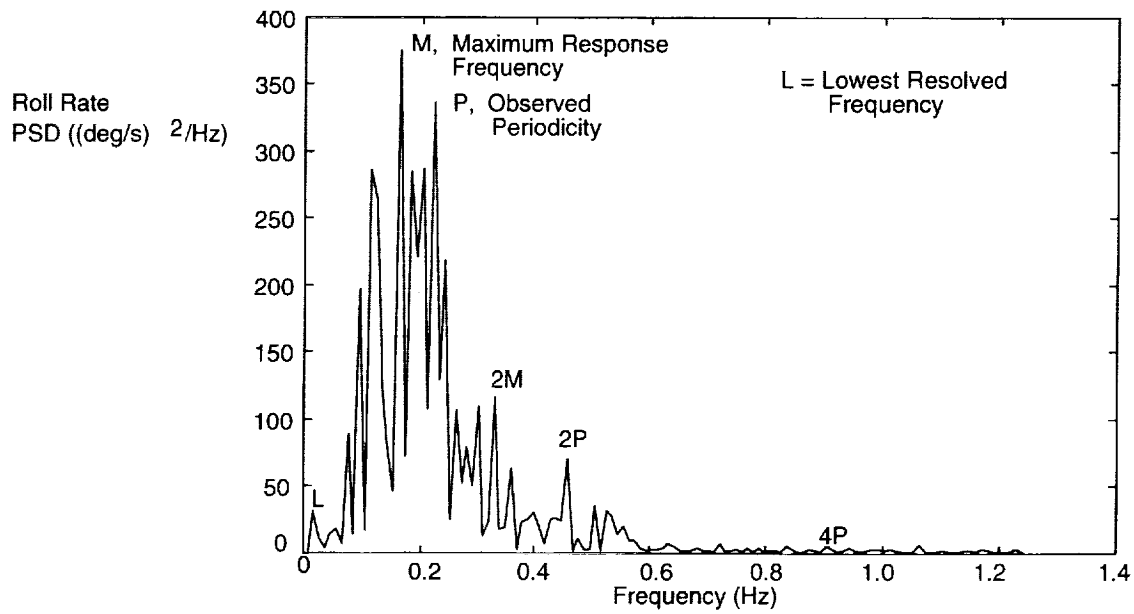
b. Norfolk Approach during Flight 809

Fig. 5, Roll Rate



Frequencies (Hz): L = 0.047, P = 0.212, 2P = 0.428, 3P = 0.640, 4P = 0.849

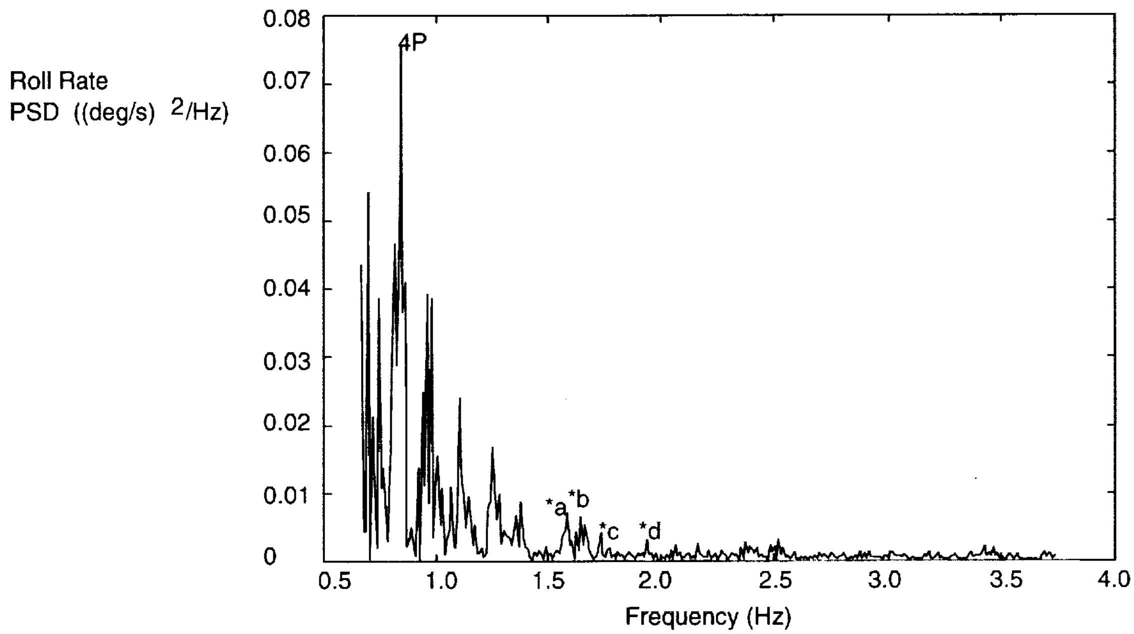
a. Level Flight during Flight 732



Frequencies (Hz): L = 0.021, M = 0.164, P = 0.227, 2M = 0.332, 2P = 0.458, 4P = 0.911

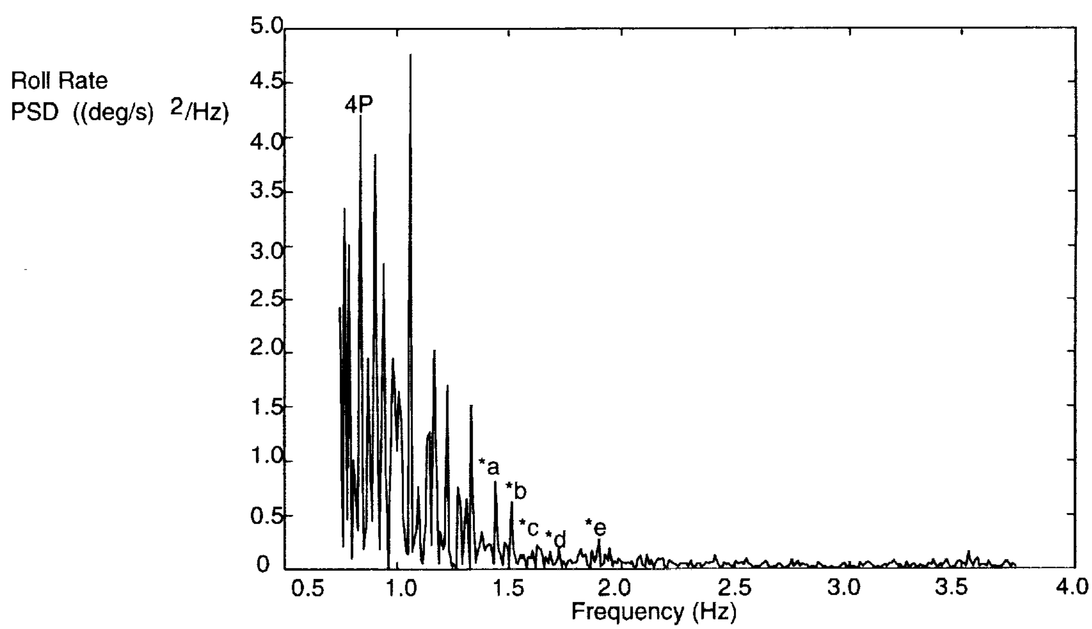
b. Norfolk Approach during Flight 809

Fig. 6, Roll Rate PSD, Low Frequency Range, (0.02 to 1.0 Hz)



Frequencies (Hz): 4P = 0.849, *a = 1.595, *b = 1.648, *c = 1.738, *d = 1.941

a. Level Flight during Flight 732

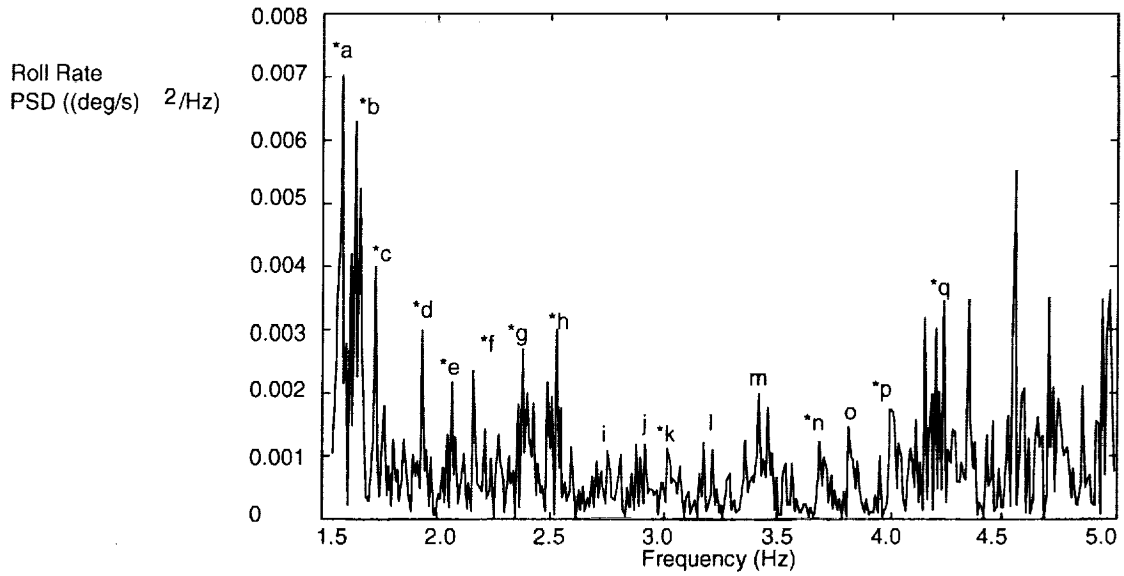


Frequencies (Hz): 4P = 0.911, *a = 1.456, *b = 1.509, *c = 1.632, *d = 1.730, *e = 1.909

b. Norfolk Approach during Flight 809

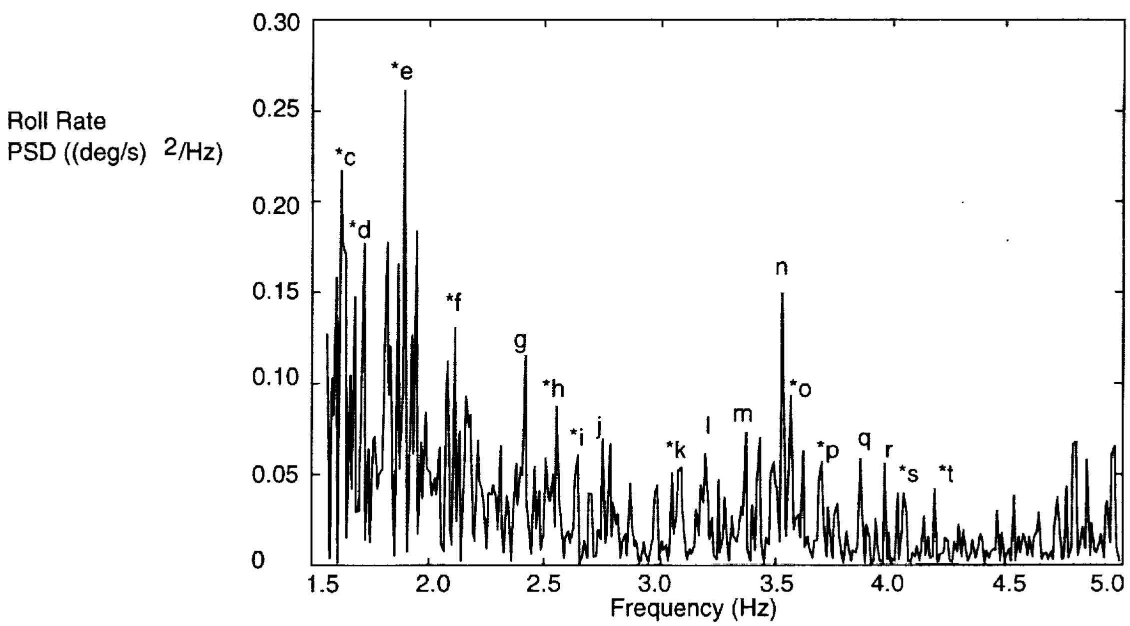
(*) Identifies frequencies which appear in PSD renderings from both Flights

Fig. 7, Roll Rate PSD, Mid Frequency Range, (0.7 to 2.1 Hz)



Frequencies (Hz): *a = 1.595, *b = 1.648, *c = 1.738, *d = 1.941, *e = 2.077, *f = 2.175, *g = 2.386, *h = 2.536, i = 2.774, j = 2.914, *k = 3.004, l = 3.182, m = 3.426, *n = 3.694, o = 3.810, *p = 4.005 *q = 4.239

a. Level Flight during Flight 732



Frequencies (Hz): *c = 1.632, *d = 1.730, *e = 1.909, *f = 2.126, g = 2.422, *h = 2.561, *i = 2.649, j = 2.758, *k = 3.090, l = 3.201, m = 3.385, n = 3.536, *o = 3.662, *p = 3.706, q = 3.866, r = 3.984, *s = 4.065, *t = 4.207

b. Norfolk Approach during Flight 809

(*) Identifies frequencies which appear in PSD renderings from both Flights

Fig. 8, Roll Rate PSD, High Frequency Range, (1.7 to 5.0 Hz)

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2001	Contractor Report

4. TITLE AND SUBTITLE
Data Mining of NASA Boeing 737 Flight Data
Frequency Analysis of In-Flight Recorded Data

5. FUNDING NUMBERS
NAS1-96013
Task Order GL28

WU 706-61-11-01

6. AUTHOR(S)
Ansel J. Butterfield

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
FDC/NYMA, Inc.
Hampton, VA 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR-2001-210641

11. SUPPLEMENTARY NOTES
This report was prepared by FDC/NYMA, Inc., under subcontract to Research and Data Systems Corporation, Greenbelt, Maryland, under contract NAS1-96013 to Langley. Technical Monitor: Charles R. Hyde; Technical Coordinator: Stanley E. Woodard.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category 05 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Data recorded during flights of the NASA Trailblazer Boeing 737 have been analyzed to ascertain the presence of aircraft structural responses from various excitations such as the engine, aerodynamic effects, wind gusts, and control system operations. The NASA Trailblazer Boeing 737 was chosen as a focus of the study because of a large quantity of its flight data records. The goal of this study was to determine if any aircraft structural characteristics could be identified from flight data collected for measuring non-structural phenomena. A number of such data were examined for spatial and frequency correlation as a means of discovering hidden knowledge of the dynamic behavior of the aircraft. Data recorded from on-board dynamic sensors over a range of flight conditions showed consistently appearing frequencies. Those frequencies were attributed to aircraft structural vibrations.

14. SUBJECT TERMS
Boeing 737, Frequency Analysis, Structural Response

15. NUMBER OF PAGES
27

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL